

# **DEVELOPING A CROSS-PROJECT SUPPORT SYSTEM DURING MISSION OPERATIONS: DEEP SPACE 1 EXTENDED MISSION FLIGHT CONTROL**

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## ***Introduction and DS1 Overview***

NASA is focusing on small, low-cost spacecraft for both planetary and earth science missions. Deep Space 1 (DS1) was the first mission to be launched by the NMP. The New Millennium Project (NMP) is designed to develop and test new technology that can be used on future science missions with lower cost and risk. The NMP is finding ways to reduce cost not only in development, but also in operations. DS1 was approved for an extended mission, but the budget was not large, so the project began looking into part time team members shared with other projects.

DS1 launched on October 24, 1998, in its primary mission it successfully tested twelve new technologies. The extended mission started September 18, 1999 and ran through the encounter with Comet Borrelly on September 22, 2001.

The Flight Control Team (FCT) was one team that needed to use part time or “multi mission” people. Circumstances led to a situation where for the few months before the Borrelly encounter in September of 2001 DS1 had no certified full time Flight Control Engineers also known as Aces. This paper examines how DS1 utilized cross-project support including the communication between different projects, and the how the tools used by the Flight Control Engineer fit into cross-project support.

## ***Scheduling Support***

In the extended mission DS1's Ace pool consisted of three past Aces who had moved on to management positions elsewhere at JPL, as well as Aces from the Cassini and Galileo projects. This section focuses on the inter-project management techniques developed for coordinating the Ace support between the three projects.

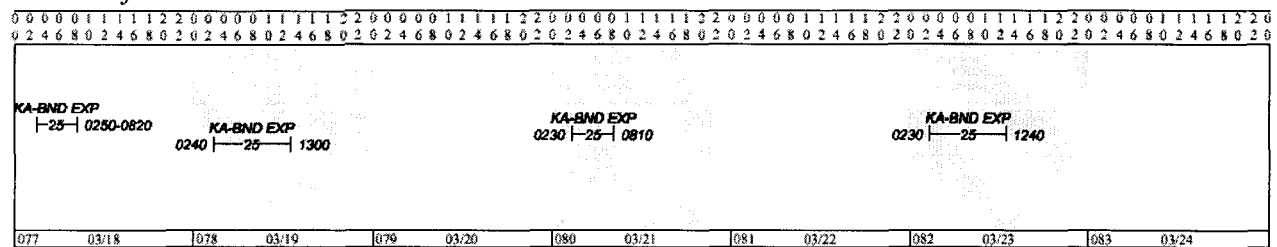
Cassini and Galileo each had their own standard method to track DS1. Flight Control Engineers from Cassini were usually “dedicated” Aces; they tracked only DS1 during DS1 tracks. Galileo Flight Control Engineers almost always tracked both Galileo and DS1 at the same time; DS1 referred to them as “multi mission” Aces. The group supervisor Aces tracked DS1 as dedicated Aces also. Exceptions to these rules occurred during important spacecraft events for any one of the three projects. During Cassini's gravity wave experiment (GWE), when Cassini was tracked for forty days continuously, the Cassini Aces would cover DS1 passes as “multi mission” Aces (tracking Cassini and DS1 at the same time). Another change came during one of DS1's “semi emergencies”, when DS1 was grabbing additional tracking time (mostly from Galileo), Galileo sent their Aces to be dedicated Aces.

## DSN Coverage

One of the challenges of scheduling Aces was coordinating DSN schedules and spacecraft event plans across three projects. The first documents to come out were usually the DSN tracking schedules. For DS1, tracking schedules showed the basic information about the track and what the DSN station was expected to provide for support. This information included commanding, ranging, telemetry or beacon tones, and what antenna the spacecraft would be using.

The DSN schedules for the other projects were also available; the DS1 Operations Engineer compared these before asking for support from the other projects. To schedule Galileo support the DS1 track needed to be at the same time as a Galileo track (for multi mission support). For Cassini, (dedicated Ace support) the idea was to find a space where there might be more Aces than Cassini tracks. Of course the final word on DS1 getting Flight Control Engineers from either project came from the Operations Engineer of that project.

### Portion of a DS1 DSN schedule



### Portion of a Cassini DSN schedule

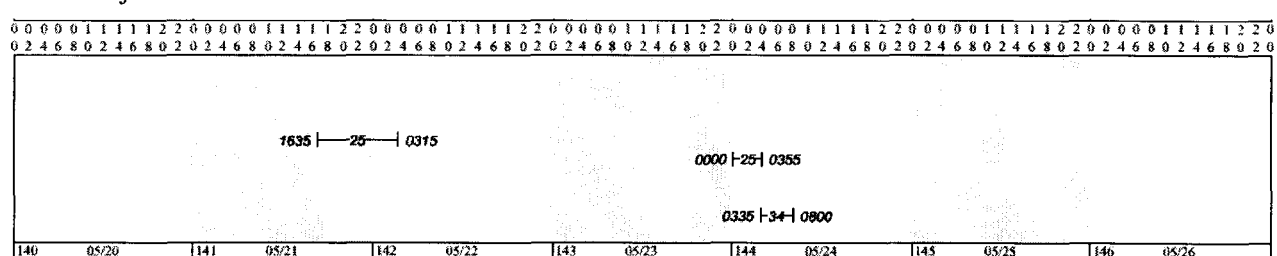


Figure 1: These examples of the DSN Schedules show how the tracking times for the two spacecraft can be compared. If these two were of the same week the resulting DSI Ace schedule may have Cassini Aces tracking the first pass of the week and maybe the third.

## Spacecraft Events

Having looked over the DSN schedules the next step for the DS1 Operations Engineer was to find out what the spacecraft team had in mind for the tracks. There was a basic list of questions that needed to be answered:

- What is the amount of commanding?
- What is the amount of interaction the spacecraft team want with the Ace?
- What mode will the spacecraft be in during the track?
- Are any unusual occurrences/anomalies expected?
- Are there any spacecraft activities for the pass?

Answers to these questions were found in the planning meetings held by the spacecraft team and in discussing the tracks with the flight director. The DKF (DSN Keyword File) and the SFOS (Space Flight Operations Schedule) were two documents produced that also answered some of the questions. For some passes the spacecraft team wanted an Ace with more DS1 knowledge and training than the cross project Aces had, in these cases one of the ex-DS1 Aces would be called in if possible.

The Operations Engineer used the knowledge of the spacecraft plans to match tracks with the type of Flight Control Engineer support needed. This then allowed the Operations Engineer to work with the Operations Engineers from the other projects to match individual people to a track.

### ***Flight Control Engineer Hardware and Software Tools***

JPL has a standard set of systems and tools for operations. This section looks at the systems and software that the Ace comes in contact with the most. There are many other software tools that have uses that the JPL developers can adjust to be specific to a project. The fact that most of the tools are set up to be project specific at first seems to create difficulties for an Ace moving from project to project. In reality, however, the changes made by the developers, to create project specific products, are often transparent to the Aces.

The VOCA system is the JPL system for operations voice communications. The procedures for using the hardware and net protocol are the same for all of the JPL projects. Each project sets up project specific nets where the positions using that net are defined by the project. An important part of Ace training on a project is to learn what positions are speaking and listening on which net so that the Ace can contact whomever they need. The nets are labeled on the VOCA boxes, and their descriptions are in the FCT procedures. Making the net descriptions and participants available in the procedures helped the Aces if they ever needed to review. However, the system used on DS1 was very simple and easy to remember. DS1 had two nets set up for the extended mission phase, "DS1 OPS" and "DS1 DSN". "DS1 OPS" was used for interaction between the subsystem teams and the Ace, but because the subsystems were all in the MSA (Mission Support Area) together the "DS1 OPS" net was only used during times of high activity. "DS1 DSN" was used for interactions between the DSN, Data Control, the Operations Chief, the COMM Chief (data and voice communications in and out of JPL), the NOPE (Network Operations Project Engineer) (when needed) and the Ace. This simple system helped the cross-project Aces because it reduced the amount of information they needed to remember.

The NOCC RT (Network Operations Control Center Real Time) is the only system that is not adapted to a specific project. The NOCC displays DSN monitor data from all stations tracking at that time. The Ace or other user (these are popular with telecommunications engineering teams also) selects the spacecraft ID or the DSN station they want to see from a list. The user then is presented with a system of displays showing different groups of data that they can move through to see what monitor data they want. This is a great tool for cross project support because the displays used are the same format for each project (except some minor differences for Galileo's telemetry system).

Most of the data needed for tracking is displayed in the DMD (Data Monitor and Display) software. DMD displays are created for individual projects by the project, however, to simplify development most of the Ace displays are based on standard displays used on other projects. Thus, the displays are all very similar across projects, making it easier for Aces to move between projects. Each project adapts the basic displays to reflect specific spacecraft information.

There are six types of DMD displays: list, message, fixed, plots, sub-alarm, and alarm. Each project tends to use the types of DMD pages for the same purposes. Most pages are built by the CAT (Computer

Adaptation Team) Team for the project. However, some of the simpler ones are put together by Flight Control Team members on an as needed basis.

Fixed pages are used for both DSN monitoring and for spacecraft systems. The spacecraft system pages are usually different as there are often differences between spacecraft systems. The DSN monitoring pages are the ones most copied between projects. One example is the DSN Monitor Data page. This page was used on both DS1 and Cassini in almost the same form. The only changes made were a few aesthetic differences. A standard use for message pages is to see that data, usually telemetry, is flowing. Which channels the project chooses to put on the page varies, e.g. DS1 chose only to show the frame count on a message page, but Cassini shows some channels of spacecraft telemetry too. List pages are usually used to display spacecraft telemetry. These are often developed by the Flight Control Team on a project. Alarm and sub-alarm pages follow a standard format, thus the only differences are in how the project sets their alarms, the size of the window, and the subsystems displayed.

The DSN monitor data is displayed in a similar manner from project to project, making it easy for Aces to move from project to project. The spacecraft data, however, tends to have unique displays on each project. What helps the Ace in this case is that most projects use descriptive names for their display windows and the spacecraft team members are willing to help the ace find the correct display or channel. The DS1 team understood this problem, and was usually good about informing the Ace or Operations Engineer before the pass that a certain page or channel that they did not usually monitor would be important in understanding the spacecraft activity.

### ***DSN Configuration***

The DSN has a standard hardware configuration for all projects. This makes cross project support easier for an Ace. However, sometimes a project will do something unusual that causes a change to be made by the DSN. One of the more well known changes was done for Galileo. They have created their own telemetry system because they are only able to use their low gain antenna, and need to use this system on every pass. DS1 asked for a few changes to be made on certain passes to accommodate some of the new technologies. Two of the technologies that required the changes in DSN support were Ka band telemetry and the Beacon Tone Experiment.

Other spacecraft in flight had Ka band transmitters when DS1 launched (Cassini is one example), but it is used by radio science and is received by the DSN station as carrier only. DS1 tested the ability of Ka band to carry telemetry. From the Ace's perspective the experience with carrier-only Ka helped them to know how the station would be configuring to receive Ka band.

The other new technology was the Beacon Tone. The idea behind the tone was that the spacecraft could send a "tone" to Earth informing the spacecraft team of its state. The tone was a particular frequency, seen as a subcarrier. The station used their open loop receiver configuration to read the frequency of the tone on an FFT (Fast Fourier Transform) display at the station. This technology was found to be useful, and so a decision was made by the DS1 project to continue to use it through the extended missions.

Getting an accurate reading from the FFT was more difficult than it sounds. Many parameters had to be set correctly in order to get the real reading, or any sign of the tone at all. Problems encountered were: the scale on the display, the number of averaged samples (four needed for a clear picture), and the station not understanding the data in terms of the spacecraft. The first two problems were usually solved by adding notes to the DSN briefing message that was given before each pass, and eventually by creating a specific briefing form for tone passes. The last problem was solved by having the DSN station fax or email pictures of the FFT display to DS1 personnel who knew of what was expected and who could examine the plots more thoroughly.

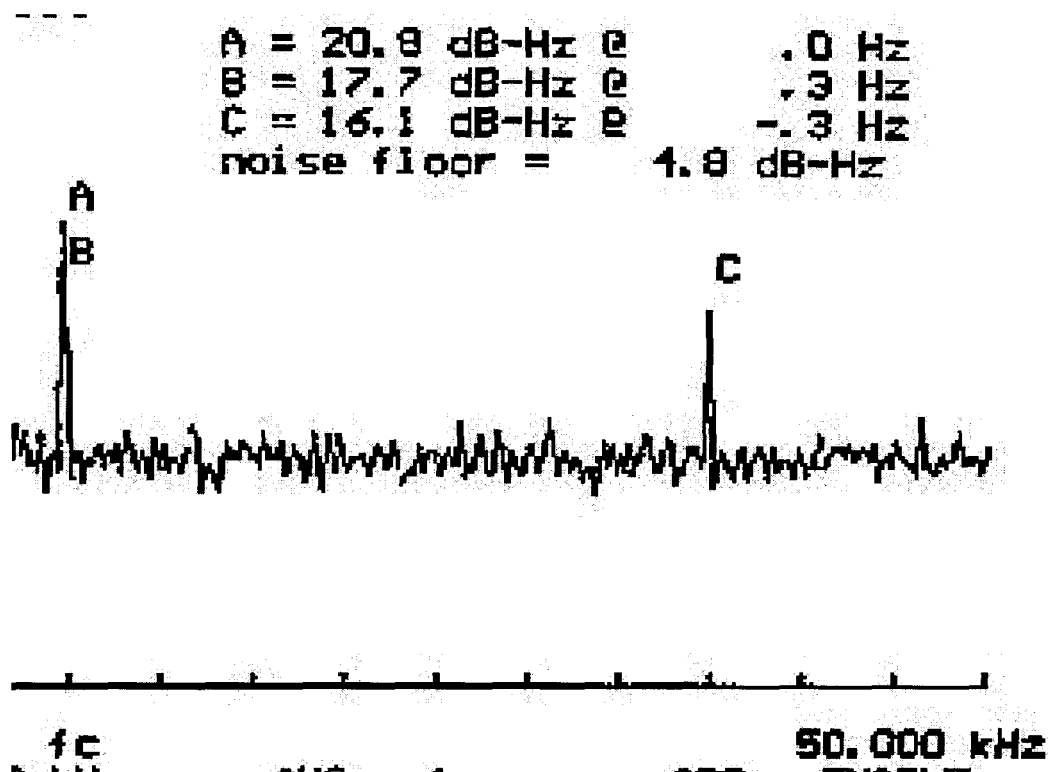


Figure 2: A portion of the FFT display that was sent to DS1 from a DSN Station. Points A and B mark the carrier's signal and point C marks the subcarrier/tone frequency. Note that there are 7 tick marks or 35 kHz between the two spikes, showing that the spacecraft is in nominal configuration.

The tone passes could be difficult for the Flight Control Engineers from the other projects because it was something they were not used to. Documentation such as the briefing message mentioned above was the best way DS1 found for communicating with the other Aces. This was not the ideal system, however. Ideally the Flight Control Engineers from the other projects would have had some actual training in tone passes from the DS1 Flight Control Engineers who understood the requirements and procedures better. That said, it seemed that the most common problem for the Aces was finding the fax machine that the pictures were arriving at. Any future use of cross project support would do well to put the fax machine in or next to the Ace console.

### ***Pre-Track Preparation***

One important job of the DS1 Operations Engineer was to make sure that the Aces were prepared for each track. This included preparing any documentation of activities during the track, personal contact with the Ace or scheduler if possible, and extending invitations to meetings during critical operations. It also included some attention to the hardware (and software programs) used by the Ace.

### ***Documentation***

An issue with having operations in multiple MSAs (Mission Support Areas) is that of moving the documentation to where it was needed. DS1 had a three-ring binder in which the information was stored

for easy transportation. The binder was divided into sections for each piece of information including general things such as the prepass briefing, telecom predicts, copies of the DKF (DSN Keyword File), SFOS (Space Flight Operations Schedule), command logs and instructions from the spacecraft team. Pass Specific items included: the portion of the NOP (Network Operations Plan) concerning tone passes, expected Alarms, and specific telemetry channels to watch. This notebook was a helpful tool for both the multi mission and dedicated Aces as it kept all of the information together in one place, even if they did often take it apart during pre-cal.

### *Making Contact*

The best way to ensure that the Flight Control Engineer was prepared for the track was to talk to them personally. The Cassini Aces usually came by the DS1 MSA to check on the briefing and track information themselves the day before the track. This made finding them easy. With Galileo, on the other hand, DS1 had agreed to provide all the pertinent information to their console, where the tracks were run from. In this case a Galileo Operations Engineer would usually look over the DS1 Ace Notebook to make sure that everything was explained.

Sometimes during critical operations the spacecraft team would want to talk to the Ace. If the track was this important usually a dedicated Ace had been requested, so this only really applied to Cassini (or the Aces-turned-managers). The DS1 Operations Engineer would inform the upcoming Ace of the problems expected during the track and let him know when the meeting was to be held to discuss the problems. The meeting was usually held the day before the track, so the Ace would often be able to make it to the meeting. If the Ace could not be at the meeting the DS1 Operations Engineer was responsible for relaying the information from the meeting to the Ace.

### *A Working and Reliable Console*

Of course an important part of every track is MSA operability. A part of the Operations Engineer's job was to ensure that the Ace workstations were operable. This included Auto Alarm Notification (AAN), the command system, and ACT (Automated Command Tracker). General Maintenance of the workstations involved reboots when needed. For the Cassini Aces who tracked DS1 from the DS1 MSA some tools needed to be up and running. To simplify tracking the NOCC RT workstations were usually left up from track to track. Commanding on DS1 required the use of both the command system and ACT. DS1 always attempted to have the commands for a pass approved and ready the day before. When this worked it gave the Operations Engineer time to bring the commands into the project directory and confirm that they were ready to be sent. The Operations Engineer was also responsible for keeping a working version of ACT running, or entering the commands himself after the track.

One difficulty was that there were workstations in three different consoles that were set up for DS1. All of these needed to be maintained by the Operations Engineer as the other Aces did not have full access for reboots, limiting their ability to work with a problematic workstation. The Operations Engineer reduced the chance that there would be problems during the tracks by checking on the workstations before a track.

### *Tracking With Cross Support: Concerns and Successes*

The Ace notebook mentioned earlier was enough information for the ace to get through an uneventful pass, grouping it in the notebook made locating the information easy. Preparing for problems encountered in a pass was a little harder as it was difficult to know beforehand what problems might be encountered. The full NOP and FCT procedures, along with telecom predicts, were kept in the DS1 MSA, where most tracks were run from.

The NOP covered all ground configuration information as well as spacecraft configuration. The NOP was used to answer any questions about configuring the station. The FCT procedures covered instructions for the Ace to run a pass. This included instructions for starting the command system and sending a command, workstation operations and other general instructions. The telecom team created spreadsheets showing predicted signal values for each track. There were also predicts for safeing configuration. These were very general and would only give an approximate value, but they were useful for identifying fault protection modes. These all helped the Aces who had not had a lot of DS1 training.

The procedures and NOP were occasionally referenced by the Ace on duty. To simplify the move to a remote console, the most used portions of these books were photocopied and put in the Ace notebook. This did create the problem that if a multi mission Ace needed to check any of the other sections during a track they would have to leave the MSA and go upstairs to get the book.

A way to improve this system on future missions would be to increase the use of electronic documents. Both Cassini and SIRTf use the web extensively as a place to store documents that need to be accessed from many different locations. The obvious drawback to this is that for a useful electronic document system Cassini and SIRTf both have teams who maintain the database. This may not be possible for a project with a small budget and team.

As has been mentioned before, many of the JPL software tools are used on multiple projects. One drawback to some of these tools is that they were not developed for a multi mission situation. One example of the problem is in the AAN (Auto Alarm Notification) tool. This program monitors alarms in DMD and pages the project when an alarm is received. The project manages the program's configuration files so that the proper people are paged for the proper alarms. Obviously an Ace whose main project is not DS1 does not want to receive pages for DS1 when tracking another project. So, to avoid putting all of the Aces in the AAN lists, an extra pager was used. This pager stayed at the console until a track began. During a track the Ace on duty could carry it with them if they needed to step off the console.

Because the Aces used by DS1 did not have a lot of time to spend on DS1, documentation became very important to real time operations. This documentation became the major source of information for the Aces to learn about the spacecraft and the project's plans. Documentation and preparation by the Operations Engineer and the DS1 spacecraft team helped to create smooth passes.

## ***Conclusion***

When faced with the need for cross-project and multi mission Flight Control support DS1 began working out ways it would be effective. The team found a number of problems in cross-project, and especially multi mission, Flight control. However, it was also found that many of the tools were ready to be used in cross-project support.

In the end, the cross-project system used by the Flight Control Team worked. Regular operations went well with, most importantly for an Ace, no major commanding errors. The spacecraft problems that occurred were diagnosed correctly, and the proper people notified in a timely manner. The cross-project team also adapted well to the spacecraft problems allowing them to be worked out quickly. Ultimately the extended mission was a success. It ended with a comet encounter that is described as "flawless" by the DS1 website. The spacecraft then continued testing its technologies for another three months when it was turned off by the flight team.

The experience of DS1 cross-project support, while sometimes frustrating, demonstrated that the concept is usable. This style of cross-project support should be considered as a viable option by other projects who find themselves in the same budgetary constraints as DS1.

### ***Acknowledgements***

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